Study of Nonlinear Mesoscale Processes: Applications to Lagrangian Data Analysis and Subgrid Scale Parameterization.

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LONG TERM GOALS

The long term goals of this proposal are to advance the understanding of nonlinear processes in ocean dynamics and the development of new methods of investigation. Special attention is given to understanding and predicting Lagrangian motions and implementing subgrid scale parameterizations.

OBJECTIVES

The specific scientific objectives of the work done can be summarized as follows:

1. Study of the evolution of particle clusters and tracer concentrations in semi-enclosed basins, focusing on the dependence of dispersion processes on the coastal boundaries, on the flux exchanges with other basins and on the structure of the internal circulation.

2. Validation and application of a new method for Lagrangian data analysis developed in the previous grant year (Bauer et al, 1997). The method allows for the estimation of mean flow and transport parameters in the presence of inhomogeneous and nonstationary velocity fields, and it is well suited for coastal applications as well as for open ocean regions with high shear.

Report Documentation Page

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3. Development of optimized methods of the assimilation of Lagrangian data for the prediction of particle motions in the ocean and for the estimation of mean flows.

APPROACH

The work is based on a probabilistic approach. It involves a combination of analytical, numerical and data processing techniques.

WORK COMPLETED

An analytical and a numerical study on the dependence of dispersion processes on boundary-initial conditions in semi-enclosed basins have been completed. The results are contained in one published paper, another submitted and a third in preparation. The practical implementation of a new method for the analysis of Lagrangian data has been completed and applied to data observed in the Equatorial Pacific and in the Adriatic Sea. The results are described in a submitted paper and in one in preparation. A preliminary study on Lagrangian data assimilation has been completed using simulated data from a numerical model.

RESULTS

The results are largely a consequence of the collaborations established during the past ARI "Random Fields in Physical Oceanography". In particular, the collaboration with mathematician L. Piterbarg (USC) has played a crucial role in the success of the study on Lagrangian data analysis and in establishing the new project on data assimilation. The main results can be summarized as follows.

1. Cluster evolution and effective transport properties in semi-enclosed basins have been studied in collaboration with E. Zambianchi (IUN, Napoli, Italy) and G. Buffoni (ENEA, La Spezia, Italy). The results are relevant to the dynamics of basins of various size ranging from semi-enclosed seas to lagoons or fjords. Also, the results indicate that this research can provide a means of characterizing ecological problems as well as physical mixing problems. The study is focused on the macroscopic properties of dispersion, i.e. on the behavior of the total concentration C(t) of a particle cluster (or a tracer) in a basin, and on the average residence time T. The results indicate that robust a-priori estimates of these quantities can be given, for a large range of parameter values, using a reduced eigenfunction expansion of the associated advection-diffusion problem. The dependence on the Peclet number, on the boundary and initial conditions, and on the characteristics of the flow field in terms of time-dependence and recirculations has been investigated.

2. New methods for the analysis of Lagrangian data have been developed and tested in collaboration with L. Piterbarg (USC, Los Angeles), M. Swenson (NOAA, Miami), and

A. Mariano (RSMAS). In the previous year, a method to separate large scale mean flow from the fluctuation field in order to compute turbulent transport parameters (Bauer et al., 1997) has been implemented. Presently, this method is being applied to observational data of several regions characterized by different dynamics and scales. The method computes the mean flow with a bicubic spline whose parameters are optimized to maintain a minimum energy level in the fluctuation at times longer than a month. This is done by minimizing a metric, M, of the Lagrangian autocorrelation amplitude at those time scales, with the additional constraint that the mean field is reasonably smooth.

The method is being applied by S. Bauer, the student supported by this grant, to the complete data set available in the Tropical Pacific and, in collaboration with P. Poulain (NPS, Monterey) and E. Zambianchi (IUN, Napoli, Italy), to an extensive data set in the Adriatic Sea. An example of preliminary results obtained for the Adriatic Sea is shown in Fig.1. The metric, M, computed for the data in Fig.1a (courtesy of P. Poulain) is shown in Fig.1b as a function of the parameter ρ of the spline. The "best" ρ is chosen as $\rho = 10$, which gives a minimum value for M and maintains a level of smoothness in the mean. The "best" ρ is used to compute the splined mean field (Fig.1c), and the corresponding residual fields, from which the "best" estimates of diffusivity are computed (Fig.1d).

3. A new study has been initiated on the assimilation of Lagrangian data in collaboration with L. Piterbarg, A. Mariano and T. Özgökmen, a post-doctoral associate at RSMAS who is supported by this grant. The purpose of the study is to determine an optimal deployment scheme of drifting buoys and the best Lagrangian assimilation strategy in order to improve prediction of particle motion in the ocean, with potential practical applications to ecological, and search and rescue problems. Preliminary experiments have been carried out in the framework of a primitive equation, 3-layer double-gyre model. The goal is to predict particle motion assuming that the mean velocity field is known and that drifting buoy data are observed in the vicinity of the tracked particle. The prediction error has been characterized as a function of the Lagrangian data density, knowledge of the mean flow, dynamical regions, and assimilation methods.

In general, the accuracy of both short-term and long-term predictions improves significantly with the assimilation of data from drifting buoys indicating the effectiveness of using in-situ Lagrangian measurements for practical problems. Two examples of predictions, obtained using an Optimal Interpolation scheme, are shown in Fig. 2: one for a particle in the gyre interior (Fig. 2a), and the other for a particle in the meandering jet (Fig. 2b). The prediction error, as a function of data density, is shown in Fig. 2c and 2d, for the two particles, respectively. When a very low density is considered, such as the WOCE requirement of 1 particle/$5° \times 5°$, the prediction does not improve significantly with respect to the prediction computed using the knowledge of the mean flow only. Instead, when the data density is sufficiently high (1 particle/$1° \times 1°$), clearly there is improvement in predictability. The difference in predictability of the two particles high-

lights the dependence on the dynamical flow regions (the gyre interior and the jet) and on the level of inherent Lagrangian chaos.

IMPACT/APPLICATIONS

These results have the potential to impact a number of topical studies.

- From the application point of view, the new methods that have been elaborated upon are of general interest and may be widely applicable in the framework of Lagrangian data analysis and of dispersion studies, especially for coastal environments. The results from the Lagrangian data assimilation study are expected to provide the necessary guidance for answering practical questions, such as, how many and how often drifters should be deployed for accurate predictions of ecological, and search and rescue problems.

- From the point of view of more basic research, the results on dispersion processes show that there is a vast range of parameter values for which the macroscopic properties can be estimated a-priori, even in the "anomalous" dispersion phase which characterizes the system before the diffusive limit is reached. The results obtained in the Lagrangian data analysis are relevant for our general understanding of turbulent phenomena. The Lagrangian fluctuation fields, in fact, appear to be appropriately described by simple stochastic models, and their properties appear to be similar in different environments, such as the open ocean and semi-enclosed seas, provided that they are appropriately rescaled. Finally, the study on particle prediction provides insights into the understanding and quantification of the link between Lagrangian predictability and chaos.

TRANSITIONS

The new method for Lagrangian data analysis is presently used in the analysis of a number of data sets: the Tropical Pacific set (with A. Mariano and M. Swenson); the Adriatic Sea (with P. Poulain and E. Zambianchi); the Tyrrhenian Sea and Sicily Channel (E. Zambianchi).

The results of the dispersion study in semi-enclosed basins are presently applied to compute estimates of residence times in the Adriatic Sea in collaboration with G. Buffoni and R. Pasmanter (KNMI, Netherlands).

The results from the preliminary data assimilation experiments presently are being compared and used as guidance for a project sponsored by the U.S. Coast Guard for sea-rescue

problems (with D. Olson (RSMAS)).

RELATED PROJECTS

Related projects are carried out with other investigators funded by ONR, the U.S. Coast Guard, and the European Science Foundation (TAO Project).

Assimilation methods for nonlinear Lagrangian processes and parameterization of turbulent phenomena using stochastic models are studied in collaboration with L. Piterbarg.

Application of the new analysis method to Lagrangian data sets is carried out with M. Swenson and A. Mariano.

A comparison between assimilation results obtained from a numerical model and results obtained from the use of observational drifter data is carried out in collaboration with D. Olson.

Particle cluster studies and the relationship between Eulerian and Lagrangian models is performed in collaboration with E. Zambianchi and G. Buffoni.

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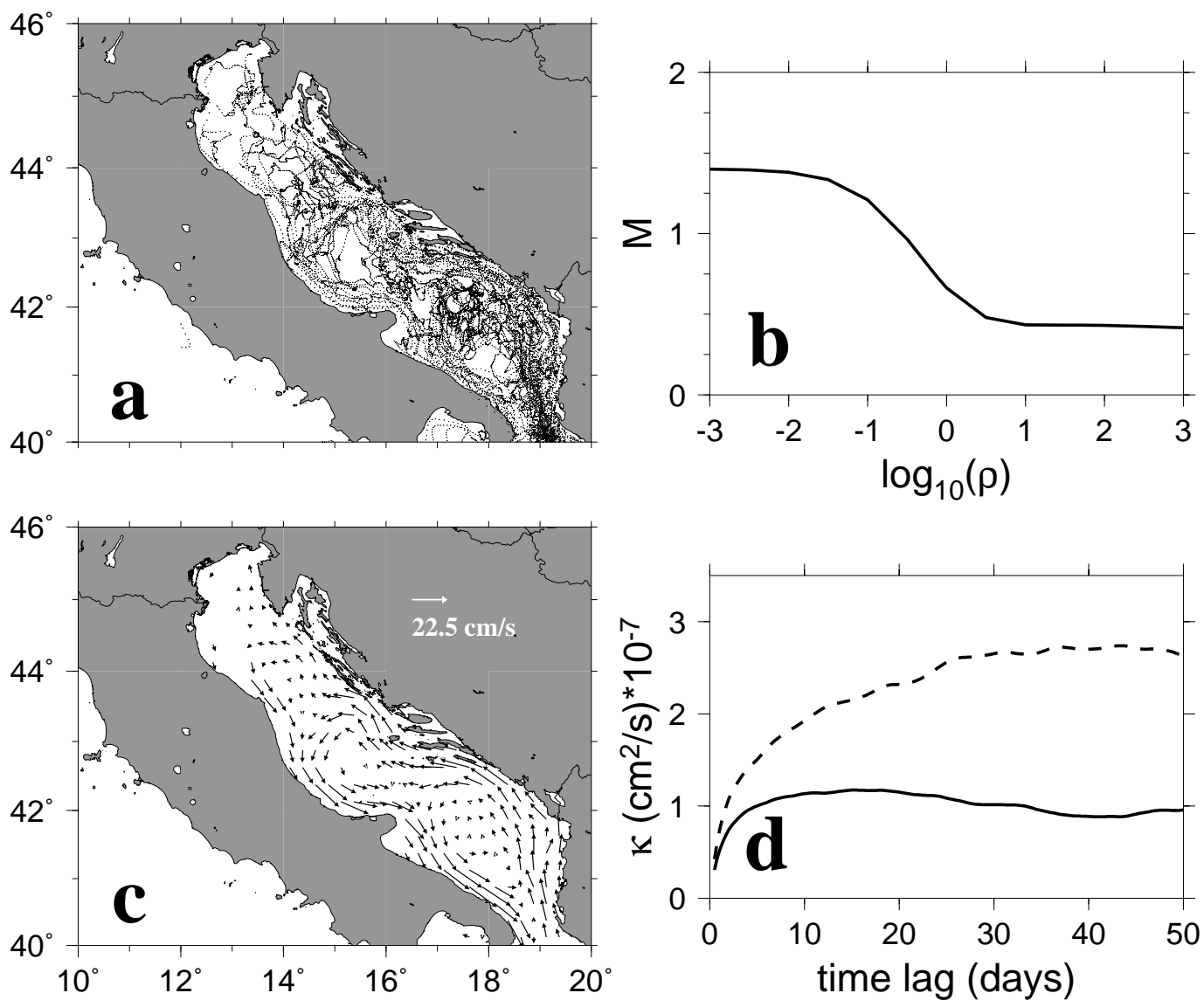
Figure 1: Results from the method developed for analysis of Lagrangian data applied to drifters of the Adriatic Sea: (a) drifter trajectories, (b) metric vs spline parameter, ρ, (c) optimized (i.e., obtained for "best" $\rho = 10$) splined mean field, and (d) zonal (solid) and meridional (dashed) diffusivity estimates.
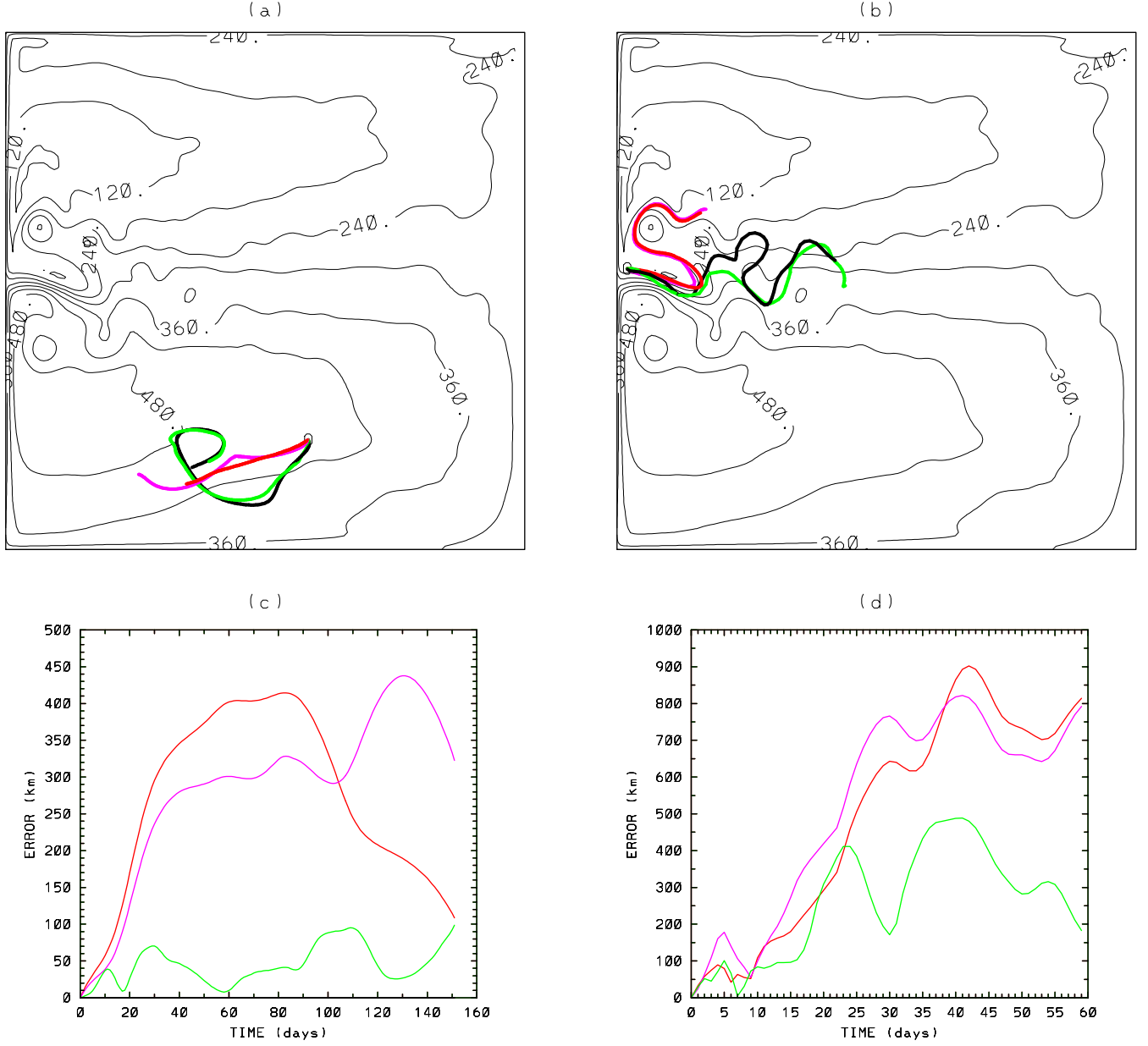
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Figure 2: Comparison of true and predicted particle trajectories released (a) in the gyre interior, and (b) in the meandering jet. Here, the black color indicates the true trajectory, and the red, purple, and green colors indicate the predicted trajectories using data density of zero (mean flow only), 1 particle per 5°×5° (WOCE requirement), and 1 particle per 1°×1°, respectively. The trajectories are superimposed on the time-averaged upper layer thickness field (contour interval: 60m). The corresponding prediction errors are illustrated in (c) and (d).